Behaviour of the clay cover of a site for storing nuclear waste of very low activity submitted to differential settlement of underlying waste: laboratory and field bending tests

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ABSTRACT: The behaviour of the cover barrier of a site for storing nuclear waste of very low activity is studied. The risk of a bending of the clay layer in case of differential settlements within underlying waste is particularly studied. Laboratory and field bending tests are performed. Influence of the water content on the mechanical behaviour of the clay is examined. Initialization and propagation of cracks are studied. The limit value of the extension strain of the clay layer without cracking is characterized. Results of field and laboratory bending tests are presented. The main aim is to optimize the use of clay as landfill cover, in terms of conditions of implementation (water content, compaction energy).

1 INTRODUCTION

Landfills have a top barrier including, in particular, a cap cover of compacted clay. In spite of the different stresses and solicitations, the capping cover must retain its physical, mechanical and hydraulic characteristics during the life of the landfill (operation and monitoring). However, this barrier meets many problems, in particular those related to its implementation and to the mechanical solicitations after closing the cell. Currently, there is a little knowledge (and no specific regulations) about the behaviour of a fine soil under low confinement (one or two meters of ground above) particularly when subjected to differential settlements. Bending tests have been realized to study the behaviour of the capping cover submitted to differential settlements. The behaviour of the clay layer is particularly studied. In case of differential settlements, cracks can occur within the clay that can modify permeability of the clay barrier (Cheng et al., 1994). So, acceptable bending, that is to say without cracks, has to be determined and the characteristics of the implementation of the clay have to be defined to optimize its behaviour in case of differential settlements, while taking into account the requirements in terms of permeability, shrinkage and density (Indraratna and Lasek, 1996). The implementation conditions, that is to say water content and compaction energy, are studied in order to optimize the characteristics of the clay layer and more precisely, the flexibility.

This paper describes the landfill. The laboratory and the field bending tests are presented. The results are discussed. They contribute to a better understanding of the mechanical behaviour of the clay material.

2 PRESENTATION OF THE SITE

Since 2003, the French radioactive waste agency ANDRA is responsible for the site for the storage of very low level nuclear waste, located in the Aube, in France. This kind of disposal facility requires a lot of precautionary measures. To ensure the radioactive waste containment, the confinement of the capping cover of the storage cells is obtained by the association of a compacted clay layer and a geomembrane (Camp et al., 2005). The cross section of the barrier is presented on the Figure 1. Characteristics of the clay are presented in Table 1. Due to the structure of the capping system, there is a risk of damage of the geomembrane due to the compaction of the overlying clay layer. So, compaction energy has to be relatively weak not to damage this one.

Waste is stored in big bags, tanks and barrels. Spaces between parcels are filled with sand. Due to the type of storage and to voids which still subsist, settlements within waste can occur. So, there is a risk of damage to the clay layer due to differential settlements within underlying waste.

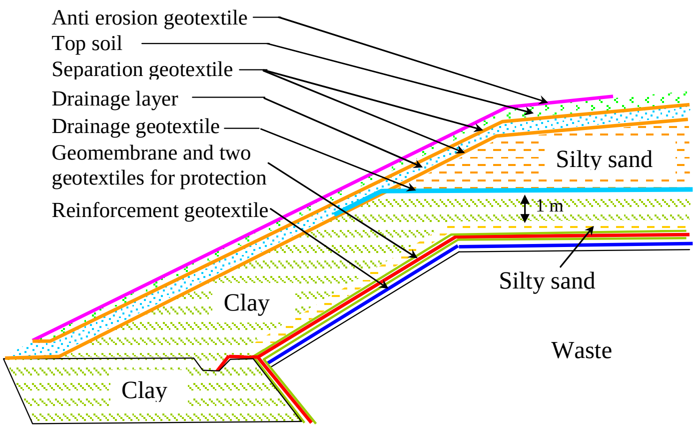

Figure 1: Structure of the cover of the storage cells

Table 1: Characteristics of the clay

Components	50% kaolinite	40% illite	10% chlorite
Size distribution	< 2µm 45 %	< 80µm 93 %	
Atterberg limits	PI 22	w_p 22%	w_l 44%
Physical characteristics	γd_{opn} 17.7kN/m^3	w_{opn} 17 %	
Mechanical characteristics	ϕ_u 20°	c_u 90 kPa	

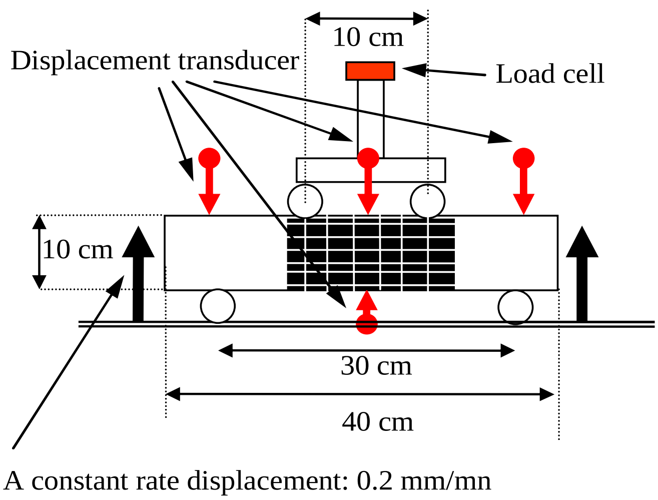

Figure 2: Laboratory bending test procedure

3 LABORATORY BENDING TEST

3.1 *Experimental procedure*

Experimental tests were carried out with the clay coming from the site presented before. Four point bending tests (see Figure 2) were selected and conducted to study the influence of the bending moment in the central zone of the sample (Indraratna and Lasek 1996) and to initiate the failure under tensile strength. This test is the nearest of the actual solicitation of the clay submitted to differential settlements. Tests are carried out on samples compacted at different energies and different water contents (Camp et al., 2006).

During the tests, photos of the middle part of the specimen, where the bending moment is constant and maximal, are regularly taken (see Figure 3). Analysis of photos permit to determine in particular the strain of the tensile fibre at the initialisation of the crack.

3.2 *Results*

Series of tests were carried out and our analysis focused on the cracking mode. The experimental results have been obtained with a good repeatability. The tensile cracking is localised in the lower part of the specimen. Strain at the initialization of cracks $\varepsilon = (\sum l - \sum l_o) / \sum l_o$ is contained between 0.04% (for w= 14%) and 0.4%, (for w = 17.5%) (deducted from the image analysis). For a same density (but different compaction energy), the strain of the tensile fibre and the deflection at the initialisation of the crack increase when the water content increases.

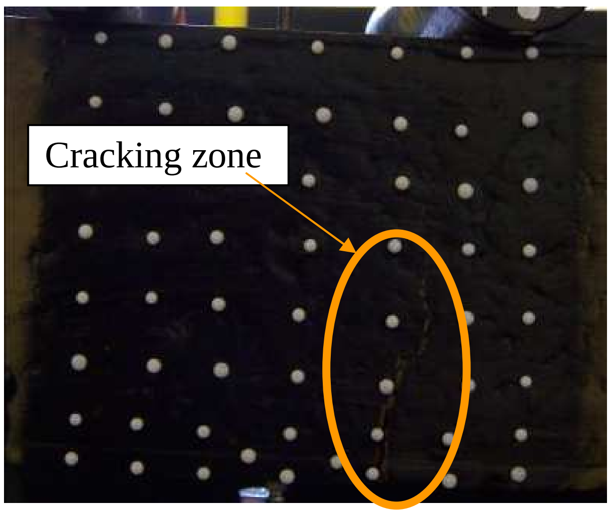

Figure 3: Central part of the beam during bending test

4 FIELD BENDING TEST

4.1 *Field test procedure*

The influence of differential settlements within the waste mass on the capping cover is modelled by submitting a clay layer to bending stresses (Jessberger and Stone, 1991; Viswanadham and

Mahesh, 2002). Two types of tests can be carried out: burst tests and settlement tests. At first, the burst tests are realized. These are inverted bending tests (see Figure 4). They don't represent the actual solicitation in case of differential settlements but these tests have been selected in order to be in position to observe the initialization of cracks that occur at the surface of the clay layer, at the level of the tensile fibre. Only the clay layer is studied.

In the settlement tests, the overall structure of the capping cover is constructed, including the geomembrane and the reinforcement geotextile (see Figure 5). To reproduce the confinement of the clay layer in the cover barrier, a load corresponding to the actual over loading in the cover system is put on the surface of the clay. In the present article, only burst tests are presented.

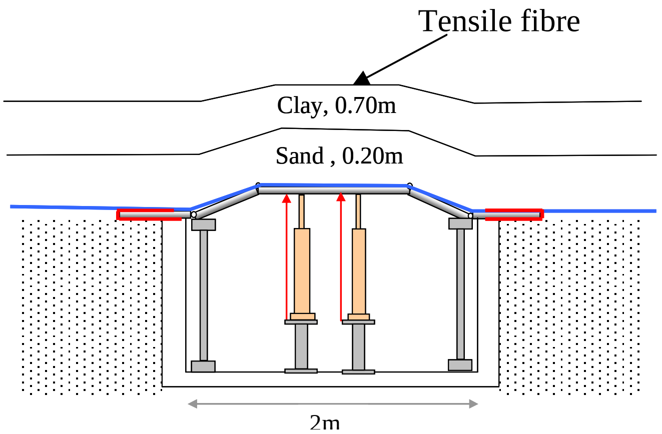

Figure 4: Burst test

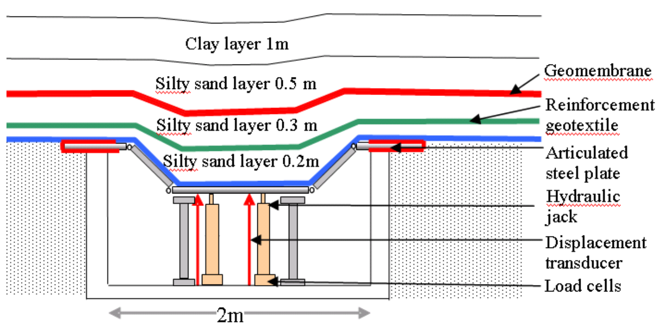

Figure 5: Settlement test

For the implementation of these tests, a rigid pit in reinforced concrete (width: 2 m) is built, and an articulated steel plate (2m * 2m) placed over the pit. Plane strain state is considered as existing for a central profile. A system of four hydraulic jacks in the pit allows the plate to reproduce local subsidence. The jacks are synchronized to ensure the same displacement of the four corners of the plate and an equal load on each jack. A series of displacement transducers and load cells monitor the jacks. The maximal vertical displacement of the plate is 0.25 m. A grid of markers is installed on the surface of the clay layer. Photos are taken during tests, allowing the measurement of the displacements of the surface of the clay (see Figure 7).

The clay used for these tests is the same one used for the capping cover (passive barrier) of the site for storing low level nuclear waste (see Table 1). Tests of characterization of this clay were presented in a former paper (Camp et al, 2005). The implementation conditions during the tests are as close as possible to the actual site conditions. Three tests are realized. Two different water contents are tested.

First, a non compacted sand layer is implemented above the articulated plate. This layer is 0.2 m thick. This layer has to prevent the punching of the clay layer during the vertical displacement of the plate and to allow an homogeneous compaction of the clay thanks to an homogeneous support. After this, the clay is kneaded and humidified to obtain the required water content. Clay is implemented in 2 layers, what are 0.3 m to 0.4 m thick (compacted thickness) and compacted with a tamping compactor.

For tests 1 and 2, the water content of the clay is 19%, that is corresponding to w_{opn} + 2%. For test 3, the water content of the clay is 20.5 %, that is corresponding to w_{opn} + 3.5%. The density of the clay is measured in many points by gammadensimetry. Roughly, they show that density increases with the depth within a layer of clay until 0.4 m. There is an influence of the support. Effectively, near the sand, that was very humid and not compacted, the density decreases. The clay in tests 1 and 2 presents the same water content but the average dry unit weight in test 1 (γd = 17.4 kN/m^3) is higher than in test 2 (γd = 17.2 kN/m^3). So, it can be concluded that the compaction energy, which is difficult to control on the site, due to the low surface of the experimental zone (see Figure 6), is not the same (see Figure 7).

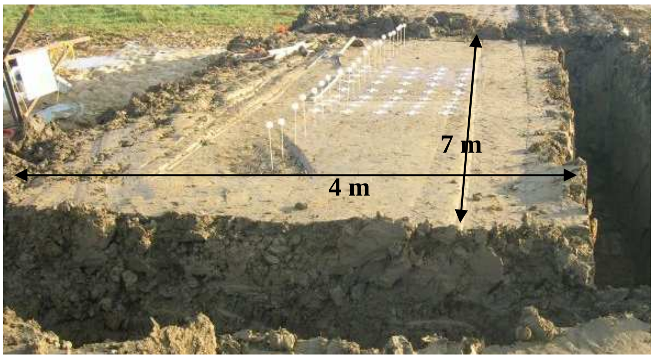

Figure 6: Global view of the field test

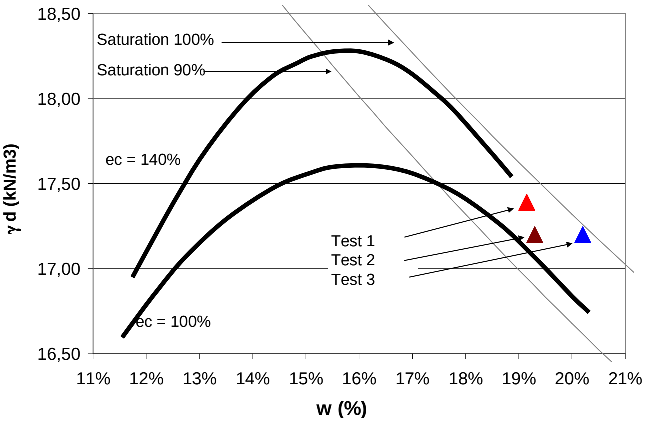

Figure 7: Characteristics of the clay for the three field tests

4.2 *Results*

Field tests have confirmed that clay is very sensitive to flexion. In all cases, cracks appear at the surface of the clay in the axial part for a displacement of the plate smaller than 3 cm.

Analysis of photos (see Figure 8) permit to determine the tension strain of the clay, at the level of the tensile fibre, at the initialization of cracks. $L_0 = \sum l_0$ is the initial distance between the two furthest markers. $L_i = \sum l_i$ the distance between the two same markers at the initialization of cracks. $\varepsilon_i = (L_i-L_0)/L_0$ is the average strain of the surface of the clay layer at the initialization of cracks. ε_i is calculated for the five lines of markers, zone assumed to correspond to a plane strain state. The mean value of ε_i is 0.6% for the test 3 (w_{opn} + 3.5%) and 0.3% for the test 1 and 2 (w_{opn} + 2%). These results confirm the observations made with the laboratory tests. In particular, during laboratory tests, the extension of the tensile fibre is calculated with the same procedure (analysis of the photos with markers). Strain at the initialization of cracks is contained between 0.04% and 0.4%, depending on the water content. The values of the strain at the initialization of cracks in laboratory and on field are very similar. So, the strain at initialization of cracks appears to be well assessed by the laboratory tests. The influence of the water content on the strain has been both shown in laboratory and in situ. In the literature, laboratory bending tests give strain at initialization of cracks between 0.1% and 0.7% (Ajaz and Parry, 1975). Settlement tests on clay and on silt give strain at initialization of cracks of 0.2% to 1.3%.(Edelmann et al., 1996)

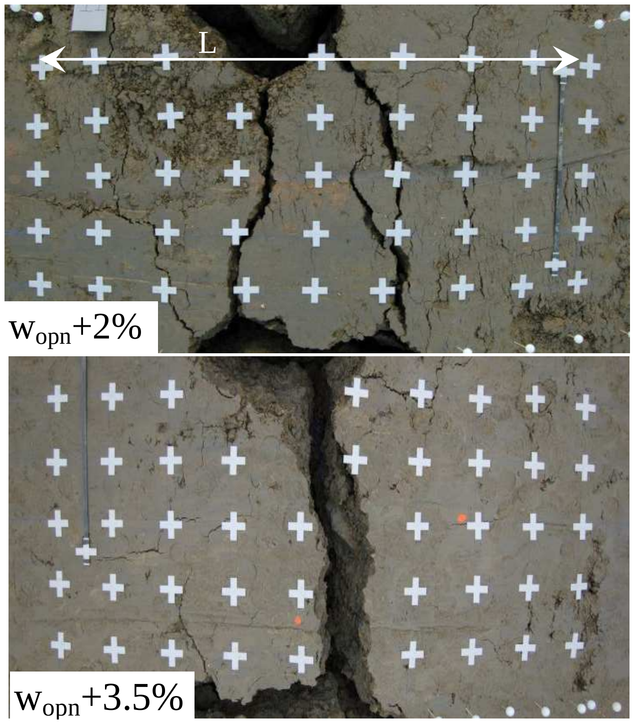

Figure 8: Final top view of the field test (vertical displacement of the plate = 25cm)

The field tests are carried on beyond the initialization of cracking. For a displacement of the plate of 10 cm, cracks are already widely open (4 cm to 7 cm). At the end of the test, a cut is realized (see Figure 9). That confirms the influence of the water content on the behaviour of the clay. Indeed, for tests 1 and 2 (w_{opn} +2%), there are two main cracks. The clay layer is damaged on the overall thickness of the layer. A void also appears between the sand layer and the clay layer (attributed to the rigidity of the clay layer) or within the clay layer (attributed to the compaction discontinuity between the two compacted layers). For test 3 (w_{opn} + 3.5%), there is only one crack that concerns only the forty first centimetres of the top of the clay layer (see Figure 9). The lower part of the clay layer is almost not damaged without any internal detachment.

Undisturbed samples have been taken in the clay layer out of the damaged area. Simple compression tests and triaxial tests (unconfined undrained tests) have been performed on these samples. The results of these tests show the influence of the water content. When the water content (higher than w_{opn}) increases and for a same compaction energy, the dry unit weight, the cohesion and the compression strength decrease. On the other hand, the vertical strain in a compression test at the initialization of shear plane increases (see Table 2.).

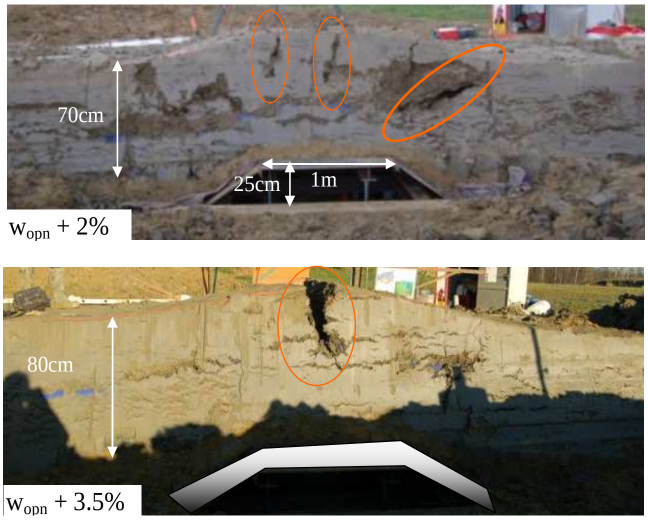

Figure 9: Final cut of the field tests (vertical displacement of the plate = 25cm)

Table 2: Results of laboratory tests on non remoulded samples (σ: standard deviation)

	w_{opn} + 2%	w_{opn} + 3.5%
γd (kN/m^3) laboratory measurements	17.39 σ = 0.17	17.23 σ = 0.17
Cu (kPa) undrained cohesion	81 σ = 8.7	71 σ = 7.7
σt (kPa) maximal compression strength	174 σ = 19	152 σ = 24
ε_s (%) strain at initialization of shear, compression test	10 σ = 3	12 σ = 3.6

5 CONCLUSIONS

Field and laboratory bending tests have been performed to characterize the behaviour of a clay layer submitted to differential settlements. Four points bending tests are performed in laboratory. The influence of the water content has been demonstrated. After that, field burst tests have been realized to study particularly the initialization of cracks in the clay layer submitted to flexion and in field conditions of implementation. All tests have shown that clay is very sensitive to flexion. But conditions of confinement of the clay layer during burst tests are not the same than in the capping system. So, cracks would probably appear later in cover system. Settlement tests will be performed in a next future to take into account the influence of the confinement for delaying the cracking and to study the global structure of the cover system.

The average strain of the stretched fibre at the initialization of cracks determined in laboratory and on site is of the same order and less than 0.6%.

Centrifuge tests are in progress in collaboration with the University of Bombay (Viswanadham and Mahesh, 2002) to reproduce the field tests. The results of the field tests and the centrifuge tests will be compared. The centrifuge tests will permit to test the influence of many parameters like the thickness of the clay, the compaction energy and the speed of the solicitation.

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